REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
April 1991	Final 1 Feb 88 - 31 Jan 91

4. TITLE AND SUBTITLE
Modulation Characterization Techniques

5. FUNDING NUMBERS
DAAL03-88-K-0037

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Southern California
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U. S. Army Research Office
P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
ARO 25707.21-EL

11. SUPPLEMENTARY NOTES
The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

This report contains abstracts of papers processed, submitted and published and of PhD theses written during the contract period.

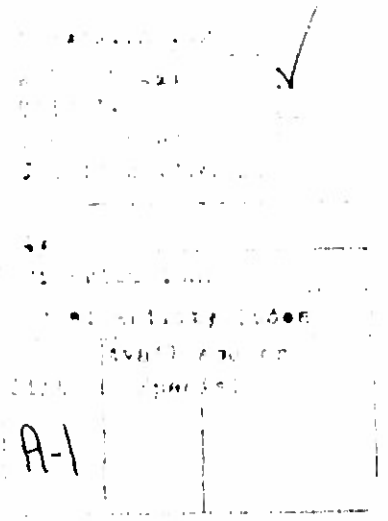
14. SUBJECT TERMS	15. NUMBER OF PAGES
Modulation Characterization Techniques, Digital Modulations, Networks	27
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

ARO 25709.21-EL

MODULATION CHARACTERIZATION TECHNIQUES

CONTRACT DAAL03-88-K-0037



FINAL TECHNICAL REPORT

1 February 1988 - 31 January 1991

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TABLE OF CONTENTS PAGE

PAPERS PROCESSED/SUBMITTED/PUBLISHED

- **On the Detection and Classification of Quadrature Digital Modulations in Broadband Noise**, by A. Polydoros & C.L. Weber
- *Proceedings International Symposium on Information Theory*, Kobe, Japan, June 17-25, 1988.
- *Abstract only*

ABSTRACT

Wideband detection of digital random signals, either of the Phase-Shift-Keying (PSK) or the Frequency-Shift-Keying/Frequency Hopping (FSK/FH) type, has been well-documented in the literature for an additive white Gaussian noise (AWGN) background. The detection rules proposed typically fall into two categories: (a) *optimal* or *near-optimal* algorithms, which are inspired and derived from a Likelihood-Ratio (LR) formulation and (b) *simple* but suboptimal *ad-hoc* algorithms, which belong to the "energy-detection" class of rules.

The focus of this paper is on the detection of Quadrature digital modulations, such as QPSK, Offset-QPSK (OQPSK) and Minimum-Shift-Keying (MSK). We first derive the optimal LR detection rule for each modulation, for both the phase-coherent and noncoherent case, assuming no epoch or frequency uncertainty. Subsequently, we quantify the optimal performance via the Gaussian distance or output signal-to-noise ratio (SNR_{out}). It is shown that no measurable differences exist between the coherent and noncoherent QPSK structures, in contrast to the antipodal (BPSK) case. This result is extended to the other modulations, indicating the advantage in covertness offered by Quadrature modulations.

Having identified the upper bounding performance of LR procedures, we proceed to investigate single-correlation-lag detection for such modulations, namely either *radiometric* or *harmonic detection* of the delay-and-multiply type. Through an elaborate analysis of the output spectral density we can identify the detectability of each modulation type at the symbol harmonics (i.e. multiples of the symbol rate), either in the baseband or around the double-carrier-frequency $2f_c$. Thus, it is shown that QPSK can only be detected at the baseband harmonics and not around $2f_c$, contrary to BPSK. On the other hand, OQPSK retains only the even harmonics at baseband and the odd harmonics around $2f_c$. The optimal delay Δ and the resulting maximum SNR_{out} are also evaluated. The potential of these methods for signal classification (i.e., modulation identification), as opposed to mere detection against noise, is also discussed.

- **On the Detection and Classification of Quadrature Digital Modulations in Broadband Noise**, by A. Polydoros & K. Kim.
- *Proceedings EUSIPCO - 88*, Grenoble, France, September 1988.

A B S T R A C T

We derive and analyze optimal and suboptimal decision rules for the detection of constant-envelope quadrature digital modulations in broadband noise. The effect of various stochastic models for the carrier phase is examined in detail, while no epoch or frequency uncertainty is assumed. The delay-and-multiply type of detectors is also considered. Finally, we comment upon the discrimination (classification) between BPSK and QPSK.

20 reprints 7/88

- **Digital Modulation Classification: The BPSK versus QPSK Case**, by K. Kim & A. Polydoros
- *Proceedings MILCOM '88*, San Diego, CA, October 1988.

A B S T R A C T

This article reports on a new BPSK/QPSK classifier and compares it to the more traditiona, ad-hoc techniques of (a) square-law classifier and (b) phase-based classifiers (weighting on the phase histogram). The new classifier is derived by approximating the likelihood-ratio functionals of phase-modulated digital signals in white Gaussian noise, hence named a quasi Log-Likelihood ratio (qLLR) rule. It is shown analytically that its performance is significantly better than that of intuitively designed phase-based rules, or the conventional square-law classifier.

20 reprints 7/88

- **Modulation Detection/Classification for Phase-Modulated Digital Signals in Broadband Noise**, by Kiseon Kim & Andreas Polydoros
- submitted for publication in the *IEEE Transactions on Communications.*

A B S T R A C T

The problem of wideband detection of phase modulated digital signals is considered. Signal models are specified, and corresponding optimal structures are derived and compared from the interceptor's viewpoint. It is shown that general quadrature phase modulation is strong

against interception. Ad hoc detectors of delay-and-multiply type are compared to the optimal detectors derived here. As an extension of optimal detector consideration, a result of detection part is utilized as a classifier between BPSK and QPSK. It is shown that the rule based on approximate optimal detector is much better than an existing rule based on phase histogram. Finally, it is suggested and strongly recommended that optimal detection consideration is very useful not only for simple detector design but also for simple classifier design.

1 preprint 1/89

- **Modulation Classification for SQPSK vs. 2^kPSK**, by Y.K. Kim & C.L. Weber
- submitted to *MILCOM '89.*

A B S T R A C T

In this paper, a general approach for the modulation classification is developed by utilizing the *Spectral Correlation* domain. The developed algorithm can be applied to a general modulation classification problem where different modulation candidates have different spectral correlations. As a specific example, classification between the SQPSK and 2^kPSK ($k \geq 1$) is considered in detail. For comparison purposes, the SQPSK/2^kPSK classification problem is approached also in the *Likelihood Functional* domain and an upper bound of the SQPSK/2^kPSK classifiers is obtained. These classifiers are developed under an additive white gaussian noise, unknown carrier phase and unknown epoch environment. Emphasis is placed on low SNR. The performance of the classifier is described by the detection probability for a fixed rejection probability.

1 preprint 1/89

- **A Probabilistic Interpretation of Spectral Correlation and Its Application to Signal Classification**, by Y.K. Kim and C.L. Weber, submitted for publication *IEEE Transactions on Communications.*
- 1 preprint 7/89

A B S T R A C T

The Spectral Correlation (SPCR) is precisely defined in a probabilistic way, and its equivalence to the original definition of SPCR is shown. A probabilistic procedure for calculating the SPCR is developed and used to obtain actual SPCR's of several signals. The SPCR is viewed as a generalized version of the Power Spectral Density (PSD) and can be calculated using only the mathematical tools necessary to calculate the PSD. It is shown that the SPCR contains all the information about the autocorrelation of a signal while the PSD does not. The probabilistic theory of the SPCR is then applied to a general binary signal classification problem, where the received signal has different SPCR's for different hypotheses. A general classification algorithm which utilizes all the information in the SPCR, is developed for the ideal environment (all parameters are known), the unknown phase environment, and the unknown phase and epoch environment. As a specific example, the developed algorithm is applied to the SQPSK v.s. QPSK classification problem.

- **Likelihood Ratio Test on Detection of Continuous Phase Modulation**, by Chung-Yu Hwang and Andreas Polydoros, *in preparation.*
- 1 preprint 7/90

A B S T R A C T

Continuous phase modulation (CPM), a signaling schemc with memory has become the most prosperous constant-envelope modulation scheme, which owns the efficient bandwidth property and good capability against nonlinearity. Several papers have discussed the demodulation procedure derived by Viterbi Algorithm. In this paper, we will change the viewpoint to discuss the detection problem on CPM signaling scheme. A modified version of Viterbi Algorithm has been developed in this paper to solve the detection problem and derive the optimal rule in the sense of likelihood ratio test (LRT). Besides, two sub-optimal methods have also been presented, which are comparable for different application and interest, and usually simpler to implement.

- **Gram Schmidt Process On Classification and Detection Problems**, by Chung-Yu Hwang and Andreas Polydoros, *in preparation.*
- 1 preprint 7/90

A B S T R A C T

The difficulty of nonorthogonality of frequency spacing on the classification and detection problems has been overcome by the time-limited signal version of Gram-Schmidt Process. In this paper, we derive and analyze optimal and suboptimal classification rules for BPSK vs. BFSK, and detection rules for nonorthogonal BFSK against AWGN by virtue of the Gram-Schmidt Process adjusted to time-limited signal application. Finally, we discover that all the decision rules derived upon orthogonal frequency spacing assumption still work without the orthogonalilty restriction.

- **A Generalized Signal Classifier Based on a Probabilistic Interpretation of Spectral Correlation**, by Youngky Kim and Charles L. Weber, *Proceedings of the Allerton Conference*, September 1989, Urbana, Illinois, pp. 1152-1161.
- 15 reprints 7/90

A B S T R A C T

The spectral correlation (SPCR) is precisely defined in a probabilistic way, and its equivalence to the original definition of SPCR is shown. A probabilistic procedure for calculating the SPCR is developed. The SPCR is viewed as a generalized version of the power spectral density (PSD). It is shown that the SPCR contains all the information about the second order properties of a signal in many interesting cases while the PSD does not. The probabilistic interpretations of the SPCR is then applied to a general binary signal classification problem, where the received signal has different SPCR's, i.e., different second order properties, for different hypotheses. A general classification algorithm which utilizes all the information in the SPCR, i.e., all the second order information, is developed for the ideal environment (all paramters are known), and the unknown phase and epoch environment.

- **Likelihood Methods for M-ary Digital-Modulation Classification**, by Chung-Yu Hwang and Andreas Polydoros.
- 1 preprint 7/90

A B S T R A C T

We derive and analyze some easily implementable decision rules, based on the concept of likelihood-ratio tests, for the classification of constant-envelope digital modulation schemes, such as MPSK and MFSK. In particular, we identify a recursive log-likelihood functional (LLF) for the classification of all MPSK signals. This is the only known decision-theoretic

rule to date for such signals, and its performance is shown to be better than some existing heuristic rules, such as the phase-histogram method.

- **Statistical Analysis of the Wigner-Ville Distribution with Applications to Wideband Detection**, Bassel F. Beidas and Charles L. Weber, to be presented at *MILCOM '90*, Monterey, CA., October 1990.
- 15 reprints 7/90

A B S T R A C T

We introduce a time-frequency statistical description of the Wigner-Ville distribution of random processes which exploits the statistical parameters constituting the Karhunen-Loeve expansion of the original time process. This provides a methodoloty for constructing Wigner-Ville based detector structures that are of analytical handiness. As an illustration of the utility of this statistical analysis, we propose an algorithm for detection of weak signals of unknown parameters that are obliterated by additive wideband Gaussian noise. This algorithm utilizes samples from an orthogonal function expansion in the time-frequency domain, the performance measure of which is ascertained. Theoretical evidence is produced of its potential superiority over the radiometer (an energy-detecting device). Monte-Carlo simulations are then implemented to demonstrate its effectiveness and display probability performance curves as evoked by the Neyman Pearson philosophy.

- **A Soft Decision Decoding Algorithm for Convolutional Codes**, by Chih-ping Hsu and Charles L. Weber, to be presented at *MILCOM '90*, Monterey, CA., October 1990.
- 15 reprints 7/90

A B S T R A C T

Bit Decoding Algorithms of Convolutional Codes are used for real time systems. A syndrome decoder has been shown to be an efficient way for very high data rate implementation. With soft decision signals, the performance of the decoder can be improved. Utilizing a Signal-Plus-Noise Channel Model to specify a Q-level quantized AWGN Channel or a Binary Input Q-ary Output Channel, we are able to define both errors and syndromes through an r-dimensional binary vector representation. A Q-level soft decision syndrome decoder is built based on this model. The binary vector representation is found to be unique under this construction.

- **Nonlinear Communication System Simulation via Conditional Importance Sampling**, by Tao Chen and Charles L. Weber, to be presented at *MILCOM '90*, Monterey, CA., October 1990.
- 15 reprints 7/90

A B S T R A C T

A recently proposed version of *importance sampling*, designated as *conditional importance sampling*, or CIS, is applied to the simulation of bit error rate in nonlinear digital communication systems. *Importance sampling*, or IS, is a variation of *Monte Carlo* which increases the simulation speed by altering the input density functions and weighting the output to have an unbiased estimator. CIS adaptively changes the bias applied to some input noise probability density functions, or pdf's, conditioned on the realization of other random input sources to give us more freedom in shaping the biased joint input pdf to match the optimum solution. The principles of applying this method to nonlinear systems are discussed through a simple system. And the resulting estimator performance of CIS are evaluated on a more complicated one. The improvements over standard *Monte Carlo* and regular (unconditional) IS are significant.

- **Likelihood Classification of QAM Signals and Comparisons**, by Chung-Yu Hwang and A. Polydoros, submitted for presentation at MILCOM '91.

A B S T R A C T

In this paper, we address the problem of constructing classifiers of digital QAM communication signals, starting from the likelihood functional (LF) of such signals in additive white Gaussian noise (AWGN). We first assume known symbol timing and carrier frequency, and we then relax the timing assumption by introducing a staggered structure, which averages over the symbol timing ambiguity. In order to make the resultant classification rules easier to implement and to reduce complexity, we make some reasonable simplifications on the theoretical rule to obtain certain suboptimal versions. We also show that such rules attain good performance in medium-to-low SNR environments. We compare this performance to two other more traditional QAM classifiers, the M^{th}-law nonlinearity approach, and the feature-extraction approach. The former raises the signal to the M^{th} power and detects the energy around the M^{th} multiple of the carrier frequency, whereas the second selects the phase and amplitude estimates as the two features. It is shown that a particular suboptimal version of the LF rule, which we call the q_p classifier, is closely related to the M^{th}-law rule, both in terms of implementation and performance.

- **Blind Deconvolution using a Maximum Likelihood Channel Estimator**, by Monisha Ghosh and Charles L. Weber.
- 15 reprints 2/91

A B S T R A C T

The literature to date has suggested the use of an adaptive transversal filter and an appropriate cost function to combat the effects of intersymbol interference, when a training sequence is not available. This approach strives to directly identify the channel inverse and hence fails when there are zeros in the channel frequency response. In our approach, we endeavor to solve the problem of blind equalization in two steps. First, a maximum-likelihood estimate is made of the unknown channel from the received data alone. These estimates are then used in a maximum likelihood sequence (Viterbi) decoder to recover the transmitted digital message. Simulation results show that the probability of error obtained by this approach is *comparable* to that obtained with a Viterbi decoder operating with known rather than estimated channel symbols.

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Technical Meetings

James Mulligan, Steve Rhodes and Rich Poisel from the U.S. Army Center for Signal Warfare, visited the University of Southern California on November 29, 1988, to meet with Dr. Charles Weber, Dr. Andreas Polydoros, Dr. Lloyd Welch and research personnel working for this Contract. The following agenda provides topics that were presented and discussed at this meeting:

11:00 a.m. General Discussions

Afternoon Presentations

Andreas Polydoros Likelihood Ratio Considerations for PSK Detection/Classification in AWGN: The Synchronous Bounds.

Kiseon Kim Likelihood Ratio Considerations for PSK Detection/Classification in AWGN

Synchronous:

Phase Based Rule

GLLR

Comparison

Asynchronous:

Square Law

Youngky Kim Modulation Classification for Phase Modulated Signals - The Spectral Correlation Approach.

Monisha Ghosh Comments about "On Minimum Entropy Deconvolution," by David Donoho, *Applied Time Series Analysis II*, Ed. David Findley, 1981.

Additional Topics:

Status of May '89 Workshop

Tracking/Detection

Status of Optical Communication & Optical Signal Processing

Neural Networks for Modulation Classification

Benveniste - Paper in French

Higher Moments

- G. Giannakis Disc. and Paper

CSI-ARO Workshop on Advanced Communication Processing Techniques

A technical workshop on "Advanced Communication Processing Techniques" was organized and held in Ruidoso, New Mexico, May 14-17, 1989. Dr. Charles Weber's participation involved the organization of a session on **Modulation Characterization**. Details of presentations follow:

Dr. Charles Weber Organizer, USC.

Dr. Bart Rice "Automatic and Interactive Signal Classification" *Lockheed Missile and Space Co.*

Dr. Edward Satorius "Application of Neural Networks to Signal Sorting", *Jet Propulsion Laboratory.*

Steve Stearns "Statistical Pattern Recognition versus Model-based Approaches to Signal Classification", *Technology for Communications, International.*

Mark Wickert "Modulation Characterization using Rate-Tone Generation Systems", *University of Colorado.*

Proceedings of this workshop are being prepared and will be distributed to attendees and ARO by the end of this year.

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Technical Meetings

Weekly or bi-weekly student research seminars are held as part of our ARO-based project. Students are assigned to present their research results and lead the discussions. The following is a list of participating students and their current areas of research.

NAME	TOPIC
Youngky Kim	Modulation Characterization; ML & Spectral Correlation
Tao Chen	Conditional Importance Sampling
Chih-Ping Hsu	Soft Decisions of Convolutional Codes with Kindel Feedback Decoding
Keith Hathaway	Optical Signal Processing in Communication Receivers
Don Pace	Generalized T-F Representations Applied to Modulation Characterization
Bassel Beidas	WVD - Wigner Ville Distribution Applied to Modulation Characterization, and maybe Sonar also
Monisha Ghosh	Blind Equalization, # Channels in a NB Channel
David Rollins	Effect of Excess Modulation on the Estimate of Symbol Rate and Symbol Sync.
Mark Maier	Wideband Spread Spectrum Radar
Fred Jones	FH Acquisition

Further Activities

1. **Monisha Ghosh - Blind Equalization** - Monisha is examining a new performance criterion for developing a blind equalization algorithms. It is working quite well, in fact better than Sato's algorithm and its extensions, but only for some channels. We are now in the process of evaluating this on a wider variety of channels and making a more in depth comparison with Sato's algorithm.
2. **Bassel Biedas - Wigner-Ville Distribution (WVD)** - The primary effort here is to utilize the WVD when the class of waveforms that is to be classified is MFSK. An important theoretical result has been obtained, which will streamline the development of WVD algorithms for modulation characterization. These algorithms will be compared to SPCR and Ambiguity Function approaches to modulation characterization.
3. **Don Pace - Generalized Time-Frequency Representations (GT-FR) of Modulation Waveforms** - Don is attempting to develop optimal detection and modulation classification algorithms in terms of GT-FR. The goal here is algorithms which are significantly less sensitive to unknown parameters. Performance comparisons will be carried out as a function of the extent to which certain waveform parameters are not known.

Ph.D. Theses

On Power Spectral Densities of Modulated and Coded Digital Signals via Ergodic Markov Modeling

by
Ching Chuang

- Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute, Report *CSI-88-07-01*, May 1988.

A B S T R A C T

Several methods have been proposed for the calculation of the spectral characteristics of modulated and coded digital signals. However, little attention has been given to the appropriate algebraic structore of the general modulation and encoding formats. Since, in digital communication, these schemes may generally be represented by a finite state synchronous sequential machine, a generalized method for evaluating power spectral density can be achieved by expressing their characteristics through ergodic Markov modeling, which is the first and most important step in this method.

One primary thrust of this paper is to rigorously derive the mathematical theory of discrete and continuous spectral components of ergodic Markovian models. The existence problem is proved by using the concepts of: (i) the generalized function for the discrete component; (ii) Jordan decomposition of the transition matrix for the continuous component. From these concepts closed-form expression for the power spectral density is developed. It is shown that an eigenvalue equal to one and of multiplicity one belongs to all of the ergodic Markov transition matrices; in addition it has no effect in the spectral computations. Furthermore, zero is the only multiple eigenvalue of the transition matrices for most of the schemes. The general theory becomes particularly simple due to above results.

The general conclusions are applied to PCM formats and convolutional codes for both independent and correlated input. Properties of the transition matrix of Markov models are studied and used in deriving the general form of spectral densities. The condition of not having spectral line components is considered. Also, the variation of continuous spectral density with various input statistics, format structures, and transmitted waveforms are then discussed and computed.

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On the Performance of Slotted-Random Access Networks Under Jamming

by Nikolaos-John B. Pronios

- Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute, Report *CSI-88-07-04*, July, 1988.

A B S T R A C T

In this thesis, we study the performance of slotted, monohop networks of unbuffered users, with ALOHA-type access protocol, spread and unspread, in the presence of noise and jamming. Jamming is introduced on the physical level and the throughput/delay (link level) performance of the network is studied.

The basic problem is the effective use of the finite average jamming power. The jamming effectiveness is determined through the decrease of the average throughput and/or the increased average delay of the network. In the same framework, user countermeasures hy use of different spreading/coding and/or access parameters can he determined. The jamming is *uniformly* distributed among the users and different scenarios are examined, depending on the side information availahle to the jammer.

The jammer is initially assumed to have no side information regarding the channel and the system's state. Three different jammer models are examined for this case, with the jamming action heen decided in a prohahilistically prescrihed manner always under the finite average power constraint.

The scenario where the jammer has information ahout the (unohservahle) system's state is then examined, followed hy the scenario where the jammer has information ahout the (ohservable) channel's state. Optimal choices for jamming are made, always under the finite jamming power constraint, from a class of stationary policies for these dynamic jamming procedures. Furthermore, a heuristic algorithm determining (for some cases) the optimal jamming policy is presented.

In addition, approximate methods are developed for throughput/delay performance evaluation of this type of networks. These methods are using diffusion processes for the approximation of the performance characteristics. These approximate methods can also he used for the study of systems under jamming, and are shown to he accurate for a large range of values of the parameters involved.

Andreas Polydoros' efforts on behalf of this thesis research, were supported in part by ARO.

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Open and Closed Loop Delay Estimation with Applications to Pseudonoise Code Tracking

by Kurt Koshar

• Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute, Report *CSI-88-08-11*, August 1988.

ABSTRACT

Time delay estimation of a signal corrupted by an additive white Gaussian channel is examined. The primary case of interest is when the desired signal is a deterministic, discontinuous function. The work is divided into two areas, namely open-loop and closed-loop estimation.

In the open loop section, a number of previous bounds on the mean square error (MSE) of unhiased estimates are put into perspective. A discussion is included ont he inapplicability of the Cramer-Rao bound for discontinuous waveforms. A new bound on the MSE of maximum likelihood estimators is derived by combining concepts developed hy many other authors. It is most useful for periodic square pulses and pseudonoise (PN) codes typically used in direct sequence spread spectrum communications. It is significantly tighter than previous bounds at moderate signal to noise ratios when the pulse width is much less than the period of the signal, or the observation time.

The closed loop section extends analysis began by Layland in 1969. It was possihle to find the cross correlation function that minimizes the MSE of a first order correlation loop for arhitrary transmitted signals. The result is not in closed form, however it was still possihle to gain insight by examining special cases. The most significant result of this section is that the optimal cross correlation function is not in general the derivative of the transmitted signal. In the case of discontinuous signals, there is a substantial difference hetween open-loop bounds and conventional first order correlation loops, such as early/late delay-locked loops (DLL). DLLs have a MSE that decays with the reciprocal of the signal to noise ratio, hwereas open loop bounds on the discontinuous signals suggest that the MSE can decay with the square of the reciprocal of the signal to noise ratio. This finding suggests that first order, early/late DLLs are suboptimal tracking devices. A modified tracking loop structure is suggested that approximates maximum likelihood estimation more accurately than conventional DLLs.

Andreas Polydoros' efforts on behalf of this thesis research, were supported in part by ARO.

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Performance of Fast Frequency Hopped MFSK Spread Spectrum Communication in the Presence of AWGN and Tone Jamming

by

Robert Ward White

- Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-89-05-06*, May 1989.
- 1 copy 7/89

ABSTRACT

In this dissertation, three methods are considered to determine the performance of fast frequency hopped MFSK spread spectrum communication in the presence of tone jamming. The three methods are a direct method, a characteristic function method and a discrete method with an A/D converter. A square-law receiver is used for all cases with post detection summing over the hops.

Different cases are considered for the different methods. For the direct method the binary case (i.e., $M = 2$) with two hops per symbol (i.e. $h = 2$) is considered with no Additive White Gaussian Noise (AWGN). An expression for Bit Error Rate (BER) is developed and plotted for several cases.

For the characteristic function method an expression is found for the binary case, but for an arbitrary number of hops per symbol (i.e. arbitrary h) and with the presence of AWGN in addition to the tone jamming. The expression is numerically evaluated and plotted for several cases. As is expected, multiple hops per symbol degrade performance for this case.

To improve performance, a limiter is added to the receiver prior to summing over the hops. The form of the limiter used is an A/D converter. The A/D converter also allows calculations to be performed in the discrete domain. For this method, larger values of M and h are allowed. The channel is AWGN with tone jamming. For a variety of cases, performance is evaluated and plotted. The diversity due to multiple hops per symbol is shown to improve performance with the use of a limiter. It is also whon that the clipping point of the A/D converter can be selected to give near optimum performance over a wide range of jammer levels (i.e. E_b/N_J).

Charles Weber's efforts in behalf of this thesis research, were supported in part by ARO.

Multi-Hop Frequency-Hopping Detection

by

Char-Dir Chung

- Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-89-06-04*, August 1989.
- 1 copy 7/89

ABSTRACT

The detection of a multi-hop certain low probability of intercept/frequency hopping (LPI/FH) signal with unknown signal parameters such as hop rate, timing reference, set of candidate carrier frequencies, set of carrier phases, hopping pattern, and signal power immersed in additive white Gaussian noise (AWGN) is considered. From an interceptor's viewpoint, the tolerable assumptions made herein are (1) noise level is known in advance; (2) the spread spectral band wherein the transmitted signal might exist is known; (3) minimum noncoherent orthogonal spacing in the setup of the set of candidate carrier frequencies is adopted by the transmitter; (4) each hop carrier phase and hop carrier frequency are fixed; (5) the transmitted signal's envelope is a constant; and (6) a priori knowledge of the possible hop rates is available. Since the environment under consideration is a noncooperative one, our goal is to design detection algorithms which offer both highly detectability and less signal-parameter-sensitive performance in the statistical sense from the spectral technique. Neyman Pearson criterion is employed as the design criterion. Since large implementational complexity is encountered in building up the spectral measurement extraction device, the bank of inphase and quadriphase matched filters, DFT (Discrete Fourier Transform) spectrum analyzers have been extensively used instead in real world application. However, still insufficient is the study on the statistical comparison on the output statistics generated from two mechanisms under general conditions of timing and frequency mismatch between mechanism-set parameters and transmitted signal parameters. In the dissertation, a thorough study on the issue is also pursued.
With the use of a bank of inphase and quadriphase matched filter or the DFT spectrum analyzers, spectral measurements in time domain and correlation domain of the received signal can be extracted to assemble the proposed spectral algorithms – Enveloped Maximal algorithms, Complex Envelope Maximal algorithms, Correlation-Domain Complex Envelope Maximal algorithms, and Sequential Spectral Maximal algorithms. Performance analysis and simulation results confirm that detectability-enhanced and less signal-parameter-sensitive detection performance with respect to the unknown signal parameters can be obtained by the proposed algorithms compared to those of the previously-designed detection algorithms which were designed either in an ad hoc way or under some crucial assumption on the signal parameters.
Andreas Polydoros' efforts on behalf of this thesis research, were supported in part by ARO.

Signal Classification Based on Spectral Correlations

by

Youngky Kim

- Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-90-05-05*, April 1990.
- 1 copy 6/90

ABSTRACT

Signal classification is an intermediate step between signal detection and data demodulation. It is useful for signal confirmation, interference identification and selection of the proper demodulation scheme. A general signal classification algorithm is developed in spectral domain, and applied to a modulation classification problem.
Signal classification problem is formulated as a hypothesis testing problem, i.e., for different hypotheses, the signal has different statistical characteristics. It has been agreed that the likelihood function characterizes a signal completely in a decision theoretic point of view. The likelihood function for the additive white Gaussian channel is expressed in spectral domain to establish a bridge between spectral analysis and hypothesis testing problem. It shows that the nth order spectral correlation characterizes the nth order property of the signal. Instead of developing the optimum algorithm which utilizes all order spectral correlations, a sub-optimum algorithm, called *F-SPCR algorithm*, is developed, which thoroughly utilizes the second order spectral correlation property of a signal. During developing the algorithm, only a binary signal classification is considered for the ideal, the unknown carrier phase, and epoch environments. But, more complicated scenarios are considered in application stage. As a benchmark, a simple classifier, called *single cycle classifier*, is also developed, which makes a decision based on a pure sinusoidal generated by a cross correlator. Both classifier can be applied whenever the received signal has different second order spectral correlations for different hypotheses. Emphasis is placed on low SNR. The developed algorithms are applied to the SQPSK vs. 2*PSK classification problem. As an upper bound, the exact likelihood ratio test are obtained and evaluated for the ideal environment. Performance improvement from the simple single cycle classifier to the F-SPCR classifier, and performance degradation due to ignorance of the carrier phase and epoch, are described. Further considerations are taken for i) and unknown signal and noise power environment, ii) a tone jamming environment, and iii) an unknown baud time environment: i) a SNR and signal power estimator is developed and applied together with the signal classifier, ii) tone jamming free classifiers which are not affected by the tone jamming, are developed, and iii) the effects of baud time error to the classifier are discussed.
Charles Weber's efforts in behalf of this thesis research, were supported in part by ARO.

Coding Adaptivity Issues in Spread-Spectrum Random-Access Networks
by **Thomas Ketseoglou**

- Ph.D. Dissertation, University of Southern California, Department of Electrical Engineering, Communication Sciences Institute Report *CSI-90-08-03*, August 1990.
- 1 copy 2/91

A B S T R A C T

We address the problem of adaptive coding in Spread-Spectrum Random-Access slotted networks. First, we investigate decoding methods with code combining. We show the high potential of this techniques, as well as, its decoding simplicity. Next, we consider adaptive receiver operation in Spread-Spectrum Random Access Networks. We apply the code combining technique in Direct-Sequence and Frequency-Hopping Spread-Spectrum Random Access Networks. Incremental-redundancy transmission, a hybrid type-II ARQ adaptive protocol is also examined for Freqeuncy-Hopping Systems. We show that high gains are obtained if this type of adaptive receiver operation is applied in Spread-Spectrum Random-Access Networks. Finally, we consider an adaptive transmission method, in which the coding rage is changed in accordance with each packet status. Our results indicate that no gains are obtainable by this. Thus, our conclusion is in favor of systems with adaptive receiver operation as these systems are more effective than ones with adaptive transmitter operation.

Andreas Polydoros' efforts in behalf of this thesis research, were supported in part by ARO. Thomas Ketseoglou was a full-time research assistant supported by ARO.

Annual Research Review of the Communication Sciences Institute

An annual research review of the Communication Sciences Institute was held on February 8, 1989, at the University of Southern California. Dr. Charles L. Weber presented research progress on the Modulation Characterization Project. Char-Dir Chung, Chihping Hsu and Youngky Kim presented research results for the Poster session held in conjunction with the review. The program agenda and attendee list follows.

COMMUNICATION SCIENCES INSTITUTE
ANNUAL RESEARCH REVIEW

Wednesday, February 8, 1989

Room 1, Davidson Conference Center

University of Southern California

A G E N D A

8:15 A.M.	Registration	
9:00 A.M.	Lloyd Griffiths Assoc. Dean Eng.	Welcoming Remarks
9:10 A.M.	Robert Scholtz Director CSI	CSI Events
9:20 A.M.	Lloyd Welch	"Markov Signal Generation and Signal Analysis"
9:50 A.M.	Zhen Zhang	"Information Storage Problems"
10:20 A.M.	COFFEE BREAK	
10:40 A.M.	Discussion	"The Gigabit Network Research Activities at USC" John Silvester - USC Organizer Robert Gagliardi - USC Dale Harris - Pacific Bell Vinton Cerf - CNRI
12 NOON	LUNCH	Garden Court, Commons
1:20 P.M.	Irving Reed	"Simple Decoding of the Golay Code"
1:50 P.M.	Robert Peile	"New Directions in Equalization of Band Limited Channels"
2:20 P.M.	COFFEE BREAK	
2:40 P.M.	William Lindsey	Selected Topics in Communication
3:10 P.M.	Charles Weber	Progress on the Modulation Characterization Project

3:40 P.M.	POSTER SESSION	(Until 5:40 P.M.)
	Khaled Biyari	Performance of Digital Communication Systems Employing Quadratic-Form Receivers over Time-Varying Channels
	Rong-Feng Chang	Hierarchical Routing in Mobile Radio Network
	Char-Dir Chung	Multi-Hop Frequency-Hopping Detection
	Michael Fitz	Open Loop Phase Estimator Structures and Analysis
	Elke Hendon	CFAR Sidelobe Canceler for Radar
	Chihping Hsu	Soft Decision Syndrome Decoding of Convolutional Codes
	Yu-Cheun Jou	Switchable Pseudonoise Sequence Generator Design
	Dong-In Kim	Performance Considerations for Common-Signal Spread-Spectrum Radio with Multiple Capture Capability
	Youngky Kim	Modulation Classification for Phase-Modulated Signals
	Shankar Krishnan	Adaptive Error Correction Using Neural Nets
	Ming-Jeng Lee	A Near-Optimal Design Algorithm for Self-Planning Networks
	Song-Chyau Liang	Gateway Allocation for Connecting Existing Networks
	Yeong-Sung Lin	A Distributed Routing Algorithm for Virtual Circuit Networks
	Yeeman Lo	Space-Time System Architecture for Optical Neural Computer
	Michael Rude	Linearly-Constrained Adaptive Filtering of Constant-Modulus Signals
	Syu-Je Wang	Throughput/Delay and Stability Analysis of Multihop Slotted ALOHA Networks
	Thomas Wei	Cooperative Optical Beam Tracking Analysis
	Xiaoli Yu	A Multiple Channel Detection Algorithm Using Reference Optical Images
4:00 P.M.	CSI Faculty Meeting	with Lewis Franks, Director, Networking and Communications, National Science Foundation - Davidson Conference Center, Room 223
4:15 P.M.	CSI Advisory Board	Meeting at Davidson Conference Center, Room 222
6:00 P.M.	MIXER	Faculty Center
7:00 P.M.	BANQUET	Faculty Center

COMMUNICATION SCIENCES INSTITUTE
ANNUAL RESEARCH REVIEW

Wednesday, February 8, 1989

ATTENDEES

Frank Amoroso *Hughes*	Ellwyn Berlekamp *Cyclotomics*	Jack Bricker *Hughes*	Vinton Cerf *CNRI*
Frank Chethik *Ford Aerospace*	Eric Clelland *McDonnell Douglas*	James Dupree *TRW*	Lewis Franks *NSF*
Ken Fredricks *Motorola*	John Garnett *NSA*	James Gault *ARO*	Dennis Hall *TRW*
Dale Harris *Pacbell*	T.C. Huang *Aerospace*	Keith Hurbut *Aerospace*	Gaylord Huth *Axiomatix*
David Isaacs *Applied Systems*	Thomas Kolze *TRW*	Walter Kroy *Douglas Aircraft*	James La Frieda *Aerospace*
Robert Leyendecker *U.S.Army*	Benjamin Lipshuetz *GTE*	Kuo-Hui Liu *Pacbell*	John Maul *Aerospace*
Jerry Michaelson *Signal Proc. Tech.*	John Olsen *Hughes*	Peter Pawlowski *TRW*	Roger Peterson *Motorola*
Alexander Polman *Hughes*	William Sander *ARO*	San Shanmugan *U of Kansas*	James Spilker *Stanford Telecomm.*
Steve Stearns *Tech. Comm. Intl.*	Dan Sullivan *TRW*	Charles Wheatley *Qualcomm.*	Fletcher Wicker *Aerospace*
Eliza Wojtaszek *Rand*	Robert Word *Tech. Comm. Intl.*	Marvin Wunderlich *NSA*	Chin Yuan *Pacbell*
Joseph Yuen *JPL*			

Communication Sciences Institute
RESEARCH REVIEW
Davidson Conference Center, Room 1
University of Southern California
Wednesday, February 7, 1990

8:30 am REGISTRATION

9:00 am Lloyd Griffiths — Welcoming Remarks

9:10 am Robert Scholtz — Communication Sciences Institute Overview

9:20 am Irving Reed — *Optimal Adaptive Detection of Optical Targets in Clutter from Multiple Frequency-Band Data*

9:50 am Jim Yee — *Locating Internet Gateways*

10:20 am BREAK

10:40 am Panel Session: Robert Peile (chairman), K. Sam Shanmugan (U. Kansas, Comdisco Systems), Edward Lee (U.C. Berkeley), Paul Feintuch (Hughes Aircraft Co.) — *The Future of Digital Signal Processing — A Basis for University/Industry Cooperation?*

12:00 noon LUNCH, Center Ballroom, University Hilton

1:30 pm Guest speaker: Andrew J. Viterbi, Cofounder and Chief Technical Officer, Qualcomm, Inc. — *A Spread Spectrum Approach to Multiple Access for Digital Cellular Radio*

2:00 pm Vijay Kumar — *Nonbinary Sequence Sets (Better than Gold!)*

2:30 pm BREAK

2:50 pm Eberhardt Rechtin — *Experiences Teaching System Architecture*

3:20 pmAndreas Polydoros — *Narrowband Interference Effects in a Spread-Spectrum Packet Radio Network*

3:50 pm Poster Session

K. Biyari — *Binary Communication over Random Channels: A Unified Theory*

S. Boztas — *Four-phase Linear Recurring Sequences with Good Correlation Properties*

T. Chen — *Communication System Simulations via Conditional Importance Sampling*

A.M. Chou — *Collision-Free Channel-Access Protocols for Mobile Multihop Packet Radio Networks*

K. Hathaway — *Error Performance of Optical Processing Systems*

C.Y. Hwang — *Classification of FSK Sequences*

D.I. Kim — *Multiple Capture in Spread-Spectrum Networks*

D.K. Kim — *Demodulation Error Statistics over Rayleigh and Rician Correlated Channels*

S.H. Kim — *An Optimal Filter Design for a Cross-Spectrum Symbol-Rate Detector*

Y. Kim — *Modulation Characterization Based on Spectral Correlation*

S.C. Liang — *Locating Internetwork Gateways to Minimize Nonlinear Congestion Costs*

A. Lin — *On the Performance of an ATM Switch with a Multichannel Transmission Group*

A. Patapoutian — *A (d,k) Error-Correcting Code for Magnetic Recording*

S. Rajput — *Codesigned Receiver for ISI Channels*

M. Rude — *An Untrained, Fractionally-Spaced Equalizer for Co Channel Interference Environments*

F.M. Shiao — *On Maximizing Throughputs in Multi-Hop Slotted Aloha Packet Radio Networks*

M.T. Shih — *A VLSI Design for a Systolic Viterbi Decoder*

H. Song — *On Tuscan Squares*

C.Y. Tseng — *On the Implementation of Adaptive Filters with Adjustable Linear Constraints*

M.Z. Win — *Design and Demonstration of an Optical Phase-Locked Loop (OPLL) for Free-Space Optical Communications*

S.W. Yin — *Algebraic Decoding of the (32,16,8) Quadratic Residue Code*

S. Yu — *A Detection Algorithm for an Optical Moving Target*

G. Zunich — *A Non-Linear Robust Technique for Adaptive Arrays*

4:15 pm CSI Advisory Board Meeting, Room 222

5:30 pm MIXER, Faculty Center

6:30 pm BANQUET, Faculty Center

Attendees - CSI Review

Keith Hurlbut Aerospace	Diana Johnson Aerospace	James La Frieda Aerospace	Sumner Matsunaga Aerospace
John Maul Aerospace	Jerry D. Michaelson Aerospace	Fletcher Wicker Aerospace	Herbert Wintroub Aerospace
Art Yamada Aerospace	William Sander ARO	Gaylord Huth Axiomatix	Frank Chethik Ford Aerospace
Robert Kwan Ford Aerospace	Phillip Fire GTE	Cynthia Woverton GTE	Stan Aks Hughes
Paul Feintuch Hughes	James A. Kivett Hughes	Jon Leonard Hughes	John Olsen Hughes
Alexander Polman Hughes	William Sagey Hughes	Joseph Yuen JPL	Patrick Wong Lockheed
Eric Clelland McDonnel Douglas	David Borth Motorola	Marc Brack Motorola	James Mikulski Motorola
Ray Waddoups Motorola	Dan Sullivan None	Dale Harris Pacbell	Andrew Viterbi Qualcomm
Ed Bedrosian Rand	James Spilker Stanford Telecomm.	Steve Stearns TCI	Dennis Hall TRW
Peter Joseph TRW	Eric Wiswell TRW	Edward Lee UC Berkeley	Sam Shanmugan U of Kansas
Spyros Magliveras U of Nebraska			

PERSONNEL SUPPORTED

FACULTY

Charles Weber	Principal Investigator
Andreas Polydoros	Co-Principal Intestigator
Lloyd Welch	Co-Principal Intestigator

RESEARCH ASSISTANTS

Thomas Papavassiliou	Part-time
Thomas Ketseoglou	Full-time
Youngky Kim	Part-time
Kiseon Kim	Full-time
Char-Dir Chung	Full-time
Chih-Ping Hsu	Part-time
Tao Chen	Part-time
Seok-Ho Kim	Part-time
Glen Koste	Full-time
Monisha Ghosh	Full-time
Chung-Yu Hwang	Full-time

TRAVEL

- Dr. Charles Weber travelled to Washington, DC, March 17-20, 1988, to meet with Dr. Jim Mulligan at ARO for technical discussions.
- Dr. Andreas Polydoros travelled to Kobe, Japan, June 17-25, 1988, to attend and deliver a presentation at the *International Symposium on Information Theory.* Travel was not supported by this contract.
- Dr. Charles Weber travelled to San Diego, CA, October 23-26, 1988, to attend *MILCOM '88.* He was the technical coordinator of this meeting.
- Dr. Andreas Polydoros travelled to San Diego, CA, October 23-26, 1988, to attend and deliver presentations at *MILCOM '88.*
- Dr. Charles Weber travelled to Ruidoso, NM, to chair the session on *Modulation Characterization* at the *CSI Workshop* May 14-17, 1989.

- Dr. Andreas Polydoros travelled to Ruidoso, NM, to attend the *CSI Workshop* "Advanced Communication Processing Techniques", May 14-17, 1989.
- Dr. Lloyd Welch travelled to Ruidoso, NM, to attend the *CSI Workshop* "Advanced Communication Processing Techniques", May 14-17, 1989.
- Dr. Charles Weber travelled to Warrenton, VA to meet with Drs. Jim Mulligan, Steve Rhodes and Robert Leyendecker, June 8, 1989, for technical discussions on this contract.
- Dr. Andreas Polydoros travelled to Boston, Massachusetts, October 14-17, 1989, to attend and participate in *MILCOM '89.*